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FINAL REPORT
CONTRACT NAS 8-5172
EXPERIMENTAL AB-5 GYRO PROGRAM
31 AUGUST 1963
ASTR-SF-5



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# ABSTRACT

Task 5, Contract NAS 8-5172, covered the design, development, and fabrication of experimental AB-5 gyroscopes with improved mechanical configuration and motor performance. Prototype hardware has been delivered to NASA Astrionics Laboratory for further evaluation.

It is recommended that the next phase of this gyro development program should include the fabrication (from beryllium) of complete gyro inner cylinder assemblies using the symmetrical frame concept for dual stator flywheel support. These assemblies can be fitted to existing sleeve hardware for drift test evaluation.



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# I. Introduction

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This report constitutes the final report for Task 5 (Experimental AB-5 Gyroscope Development) and covers primarily the summary and conclusions of the work performed. Much of the detailed work has been covered by previous reports and reference to these reports is made herein rather than a repetition of the data.

Task 5 can be divided into five distinct areas of investigation:

1. Motor Study and Development
2. Magnetic Shielding Evaluation
3. Design Completion of the Unit Frame Gyro and Delivery of a Prototype Unit.
4. An Analytical and Experimental Temperature Study of the Unit Frame Gyro Prototype
5. Electron Beam Welding Evaluation

All areas except the experimental temperature study of the prototype gyro have been discussed in earlier reports but are summarized or referenced in this report. Results for the experimental temperature study appear for the first time and are reported in detail herein.

Author

## II. Motor Development

### A. Induction Motors

The induction motors evaluated during this program used a single stator build up from the same 18 slot laminations used in the dual stator hysteresis motors. Two types of induction rotors were evaluated: (1) a 59 slot, squirrel cage rotor with silver bars, and (2) a solid Armco ingot iron rotor. The solid (eddy current) rotor was used primarily as a control or basis for judging the efficiency of the squirrel cage rotor.

An induction type motor was originally proposed on the assumption that it would be very efficient, would run at a constant speed, and would not experience hunting. These are inherent characteristics of the induction motor. During the actual design of the squirrel cage rotor it was discovered that the flywheel space available for the rotor was insufficient for the required volume of iron and silver. The final design was a compromise using the maximum amount of silver with the iron volume reduced to the point of saturation. Test results indicate that the resistance of the squirrel cage was still too high for good efficiency and saturation in the rotor iron resulted in high magnetizing current. The solid ingot iron rotor was actually more efficient than the squirrel cage rotor because there was no saturation, but the high resistance of the solid iron resulted in an inferior speed-torque characteristic.

It was concluded that an induction type of motor is not practical in the present AB-5 gyro and even less practical for a small split stator gyro. The original assumptions regarding an induction gyro motor are still valid; however, the gyro must be initially designed to accommodate optimum motor proportions. The present AB-5 flywheel is better adapted for a hysteresis rotor because of its relatively small size.

Results of the induction motor tests were reported in the March 1963 monthly report.

B. Hysteresis Synchronous

1. Two Pole - The best results were obtained using the GE, P-6 hysteresis material in rotor and nickel-iron laminations (Carpenter 49) in the stator. The motors tested indicated that an input power of 7 to 8 watts would be the lowest value that could be achieved with adequate safety against loss of synchronism. Since this is above the 5 watt value which was established as the desired maximum for the new unit frame gyro, the two pole operation was abandoned in favor of the 4 pole operation.

2. Four Pole - As with the two pole motor, the best results were achieved with the GE, P-6 rotor material and with the new nickel-iron stator lamination. Power input with 4 pole operation is in the 3 to 5 watt range; the variations are due to slight manufacturing differences.

Results of the hysteresis motor tests appear in the April 1963 Monthly Report.

C. Stators

In 1962 Sperry Farragut Engineering made a preliminary analysis of the AB-5 gyro motor. This analysis led to the design of a new 18 slot nickel iron stator lamination to replace the existing 12 slot lamination. The 18 slot stator, which has more slot area, is noticeably better in the 4 pole winding. In the 4 pole stator, the end turn build up does not create a problem, and the slot can be wound full. In the two pole, however, the end turn build up with a full slot is greater than the allowable space, and the advantage of the extra slot area is lost in reducing the wire size to bring down the end turn build up.

With either the 12 or 18 slot laminations, the new nickel-iron material was superior to the silicon steel.

## III. Magnetic Shielding

A desirable feature of the AB-5 gyro would be a magnetic shield to isolate the magnetic effects of the gyro motor (stators) from the pickup assembly. One phase of this task was to evaluate the feasibility of depositing Mu-metal, or some other shielding material directly on to the inner cylinder and frame. Investigations into this area resulted in the recommendation of a process called "Polyform" by the Barber-Colman Company. According to Barber-Colman a deposited thickness of .007 - .012 would achieve 85% - 97% shielding efficiency at 400 cps.

In order to evaluate this shielding process, two sample beryllium cylinders and four sample discs were sent to the Barber-Colman Company for an application. "Polyform" shielding ("Unimag 80" material) was used. The two cylinders were completed and have been forwarded to NASA for further evaluation.

The four remaining samples were returned to SFCo unfinished.

Because the magnetic shielding material does not adhere directly to a flat smooth beryllium surface but must be secured by some bonding agent such as epoxy, the shields inside the two beryllium cylinders were preformed and then bonded to the cylinders. The merits of this method of application should be evaluated under operating condition; not only for shielding effects but also for thermal stability.

In general, the "Polyform" process looks promising if there are no serious effects from the bonding process and/or thermal instability. Magnetic shielding should be incorporated in any future prototypes for a thorough evaluation under actual operating conditions.

In order to spray magnetic materials directly on the surface (without a bonding agent) it would probably be necessary to maintain a minimum surface roughness necessary for adequate adhesion such as a specified rms machine finish or an abraded or sandblasted surface.

Further investigation in this area is necessary in order to arrive at the most satisfactory method of applying and/or bonding the magnetic material.

## IV. Prototype Gyro

### A. Fabrication and Analysis

A prototype unit frame, dual stator, inner cylinder assembly was delivered to NASA on 12 July 1963. This unit was fabricated from aluminum with a gyromet (high density) flywheel rotor and GE P-6 hysteresis material. The stators were 18 slot (nickel-iron material) connected in parallel for 26 volt operation. The 115 volt operation was not practical because of the small wire size required. Construction features of the unit frame are:

+ Rigidity - the frame is almost perfectly rigid in both the axial and radial direction. In either case, the yield rate is very small compared to the yield rate of the bearings. See Figure 3.
+ Temperature Distribution - the results of the experimental temperature study verify that the temperature gradients throughout the gyro are small and the heat flow is uniform to each end of the frame. In addition, the heat from the stators flows directly into the frame and not through the ball bearings as with the single stator motors.
+ Bearing Life - this type of construction permits inner race rotation of the bearings which will add to the life of the assembly.
+ Reduction of Parts - eliminated in this design are the end bells, screws and hanger clamps. This will help not only in requiring less spare parts for kits and for assembling the motor, but also in reducing mass shift possibilities.

Because the gyro does not require helium for operation, the problems of helium sealing are removed. This simplifies the problems of power lead installation and removes the requirement for a helium injection assembly. The above factors, when combined, should result in a gyro with low thermal mass shift and with a long operating life.

B. Documentation

Prints documenting the parts and assemblies of the unit frame gyro were updated to reflect the results of the motor tests and the prototype unit fabrication and evaluation. Brownline reproducibles have been forwarded to NASA (hand carried to Mr. Panzer; reference SFCo shipment Y-1930).

## V. Temperature Study

A. Objective and Method

One of the prime objectives of the AB-5 symmetrical design concept was to achieve a more equal temperature balance throughout the gyro. Temperature gradients have a profound influence on over-all gyro performance; directly affecting the bearing life, operating temperature drift rate tolerance, drift rate repeatability, mass shift, and/or mass unbalance.

In order to determine the gradients throughout the unit frame AB-5 gyro, a prototype unit was assembled with thermocouple probes in strategic locations throughout the assembly. See Figures 1 and 2.

The inner cylinder assembly was placed in an air bearing with an air flow of 2000 cc/min for temperature stabilization. Air flow into the air bearing was controlled to 35$^{\circ}$C during the first phase of the study

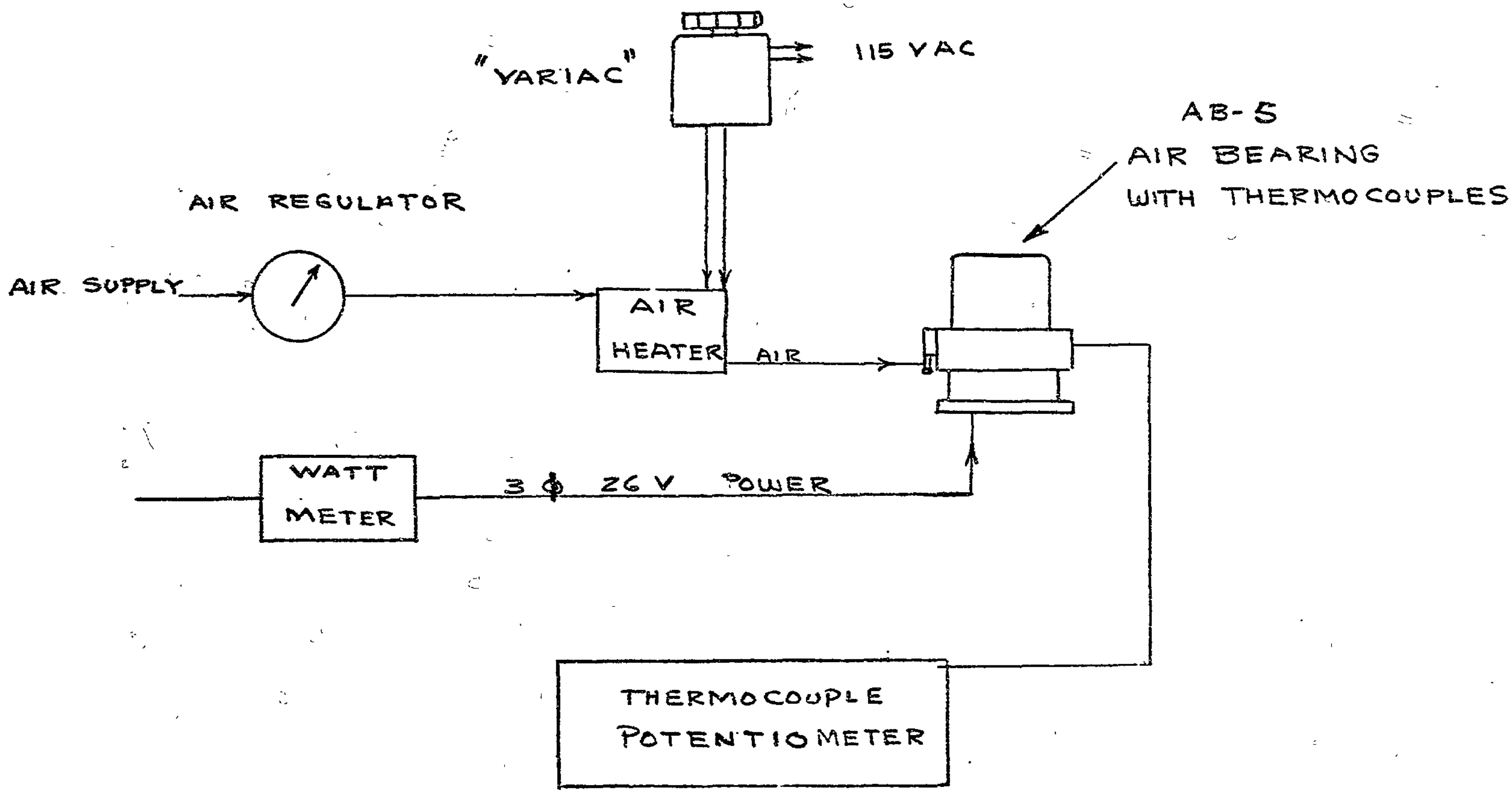
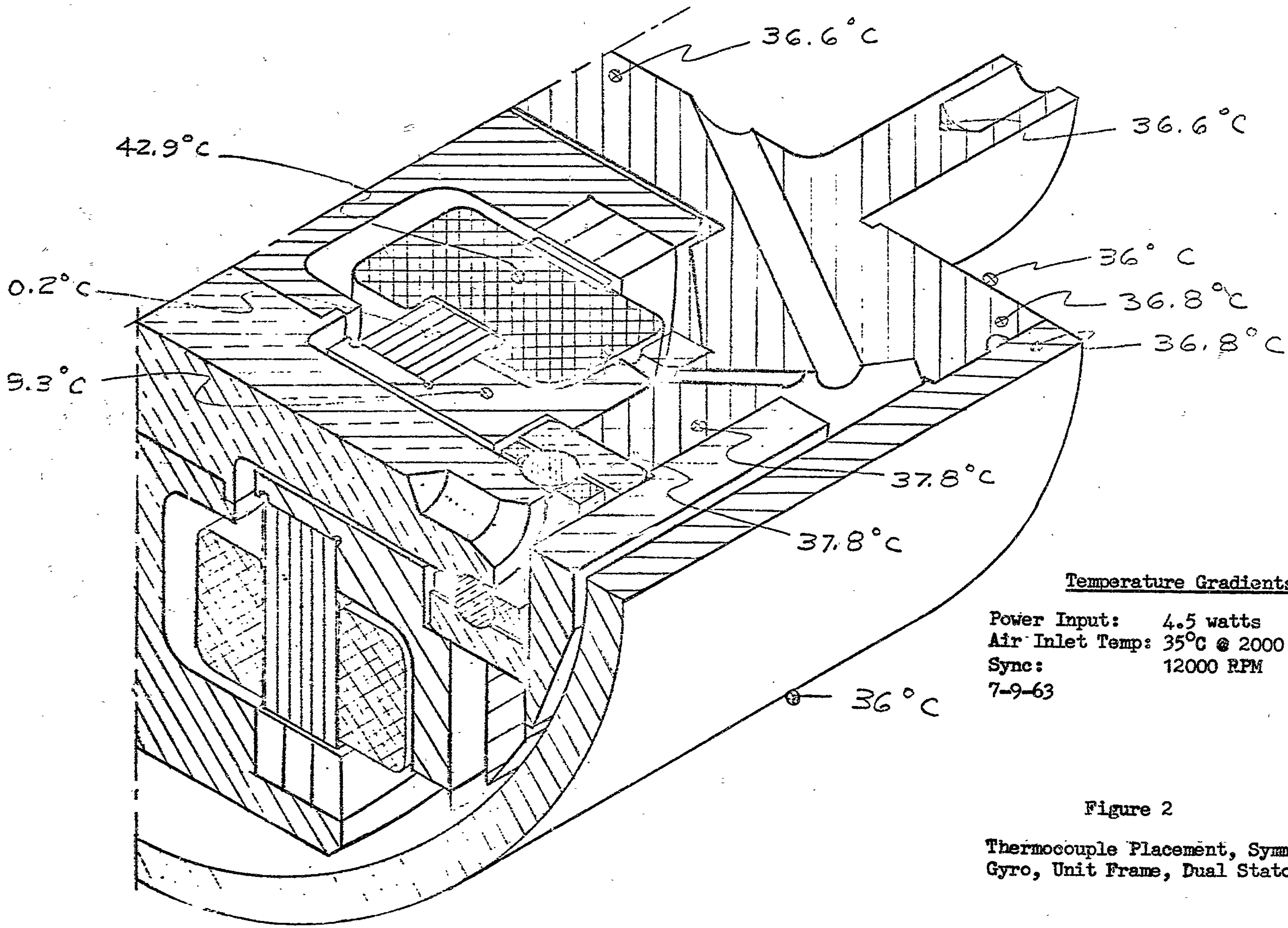



Figure 1
Temperature Study Schematic




**Temperature Gradients**

| | |
|---|---|
| Power Input: | 4.5 watts |
| Air Inlet Temp: | 35°C @ 2000 cc/min |
| Sync: | 12000 RPM |
| 7-9-63 | |

Figure 2

Thermocouple Placement, Symmetrical Gyro, Unit Frame, Dual Stator and then at room temperature (27.8°C) during the second phase.

The unit was operated at synchronous speed (12,000 rpm) with a power input of 4.5 watts for approximately 4 hours before the temperatures were recorded. The temperatures as recorded under the two conditions are as follows:

| Thermocouple Location | Air @ 35° °C | Air @ 27.8° °C |
|---|---|---|
| Stator Slot | 42.9 | 42.9 |
| Lamination | 40.2 | 40.2 |
| Stator Support | 38.3 | 38.3 |
| Bearing Race | 37.8 | 37.8 |
| Frame | 37.8 | 37.8 |
| Cover (end) | 36.8 | 36.8 |
| Frame (end) | 36.8 | 36.8 |
| Frame (hub) | 36.6 | 36.0 |
| Cylinder | 36.0 | 36.0 |

The temperatures and exact locations are shown in Figure 2.

The maximum temperature difference recorded at the various points within the gyro was 6.9°C. This occurred between the stator slot and the extreme surface of the air bearing. There was a temperature difference of 15.1°C between the stator slot and the ambient air of 27.8°C. There appears to be no significant change in temperature from the outer race of the bearings to the frame section, or across the joint of the frame to the cylinder cover. Ability to detect small differences that might exist is limited by thermocouple accuracy. Gradients of less than ½° are difficult to distinguish and are approaching the accuracy tolerance of the thermocouple.

B. Results

As intended in the original design concept, results of the temperature study verify that there is no heat flow from the shaft through the bearings. This factor in conjunction with the inner race rotation feature of the design, should add considerably to the expected life of the gyro.

There was no significant difference between the results of the air supply at 27.8°C and 35°C. Apparently the 35°C air dissipates the heat in the end housing and air inlet before the air goes through to the air bearing. In each case, the resulting temperatures were nearly the same.

1. Temperature Effect on Preload

The temperature effect on bearing preload was considered for two frame materials: aluminum and beryllium - based on the yield rate curve of the special bearing assembly purchased from the Barden Corporation. See Figure 3. The preload required to prevent "unloading" of one bearing during a 10g axial acceleration is 3 pounds. This value is used in the following calculations as the minimum preload.

A change in length between the frame and bearing shaft is expressed by the equation:

$$\Delta L = C_s(T_{os} - T_a)\, L_s - C_f\,(T_{of} - T_a)\, L_f$$

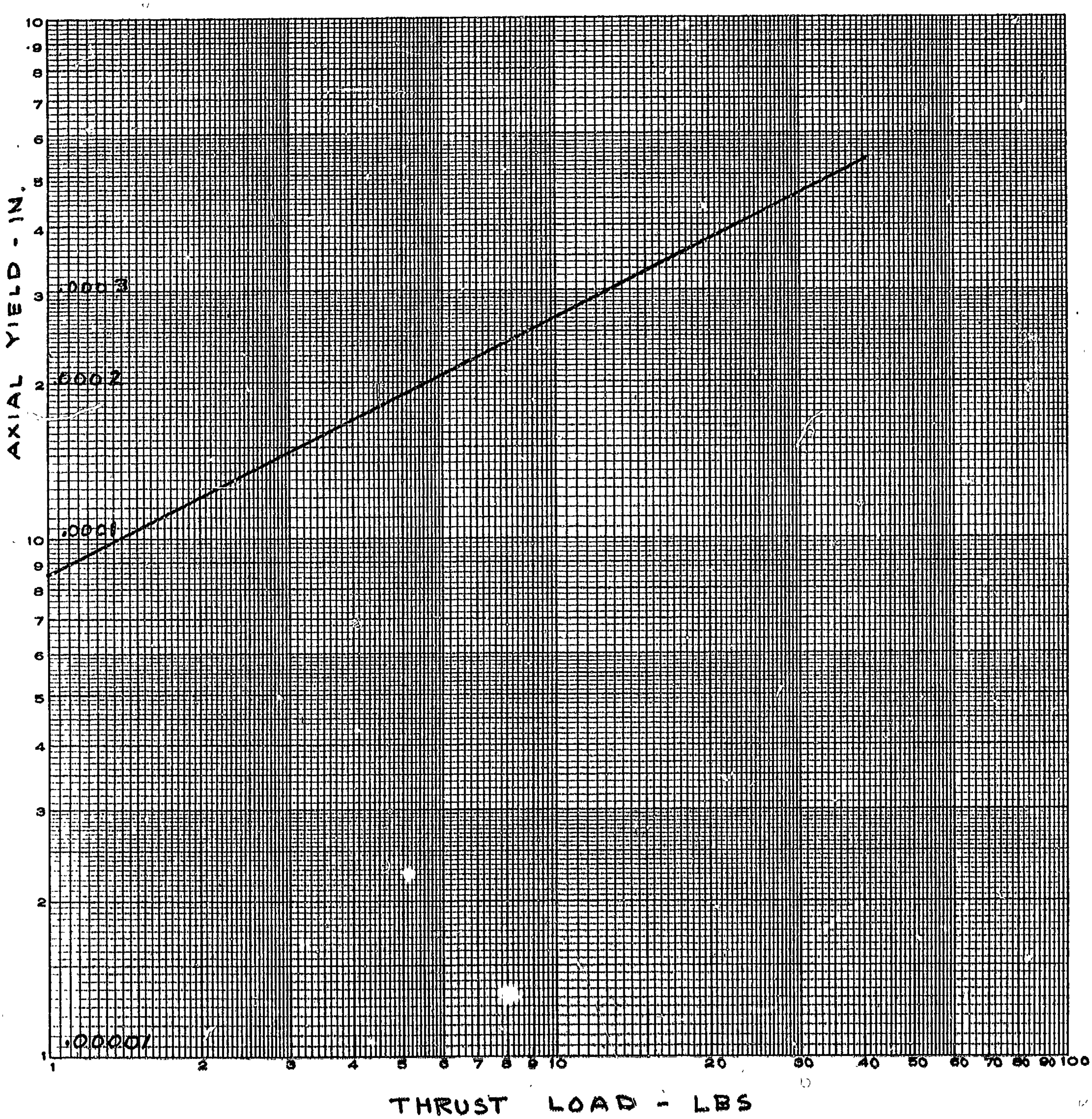



Figure 3

Single Bearing, Thrust Load vs Axial Yield where $\Delta L$ = change in length (inches)

$C_s$ = coefficient of thermal expression of 52100 steel shaft (in/in - $^oC$)

$C_f$ = coefficient of thermal expansion of frame in/in - $^oC$

$T_o$ = operation temperature ($^oC$)

$T_a$ = assembly (cold) temperature ($^oC$)

L = effective length of parts (inches)

Because the actual temperature of the shaft (a rotating member) was not measured, it is necessary to estimate an operating temperature. From Figure 3 it is observed that the temperature of parts surrounding the shaft are from 38.3$^oC$ to 42.2$^oC$. Since most of the heat is generated in the stator winding, it is unlikely that the shaft is as hot as the latter figure above. In the following analyses a temperature of 40$^oC$ is used as the shaft temperature. Operation temperature of the frame is taken as 37$^oC$ (reference Figure 2).

a. Preload Analysis for Aluminum Frame

$L_f$ = 1.7 inches $\qquad$ $L_s$ = 1.58 inches

$C_s$ = $12.2 \times 10^{-6}$ in/in - $^oC$

$C_f$ = $19.6 \times 10^{-6}$ in/in - $^oC$

$$\text{Then} \quad \Delta L = 12.2 \times 10^{-6} (40 - 27.8)\, 1.58 - 19.6 \times 10^{-6}\, (37.0 - 27.8)\, 1.7$$

$$\Delta L = -70 \times 10^{-6} \text{ in. (preload decreasing)}$$

From the yield curve (Figure 3) a change of $70 \times 10^{-6}$ inches($35.0 \times 10^{-6}$ per bearing) causes a decrease in preload of 1.35 lbs (using 3 lbs as the original setting).

In order to achieve an operating preload of 3 lbs, the "cold" preload must be set such that the axial deflection (single side) is 35.0 x $10^{-6}$ inches above the 3 lb. deflection value. Referring to Figure 3 it can be determined that the proper "cold" preload setting is 4.6 lbs.

b. Preload Analysis for Beryllium Frame

$(C_f = 12.4 \times 10^{-6}$ in/in - °C)

$\Delta L = 12.2 \times 10^{-6} \times (40 - 27.8)\ 1.58 - 12.4 \times 10^{-6}(37.0 - 27.8)\ 1.7$

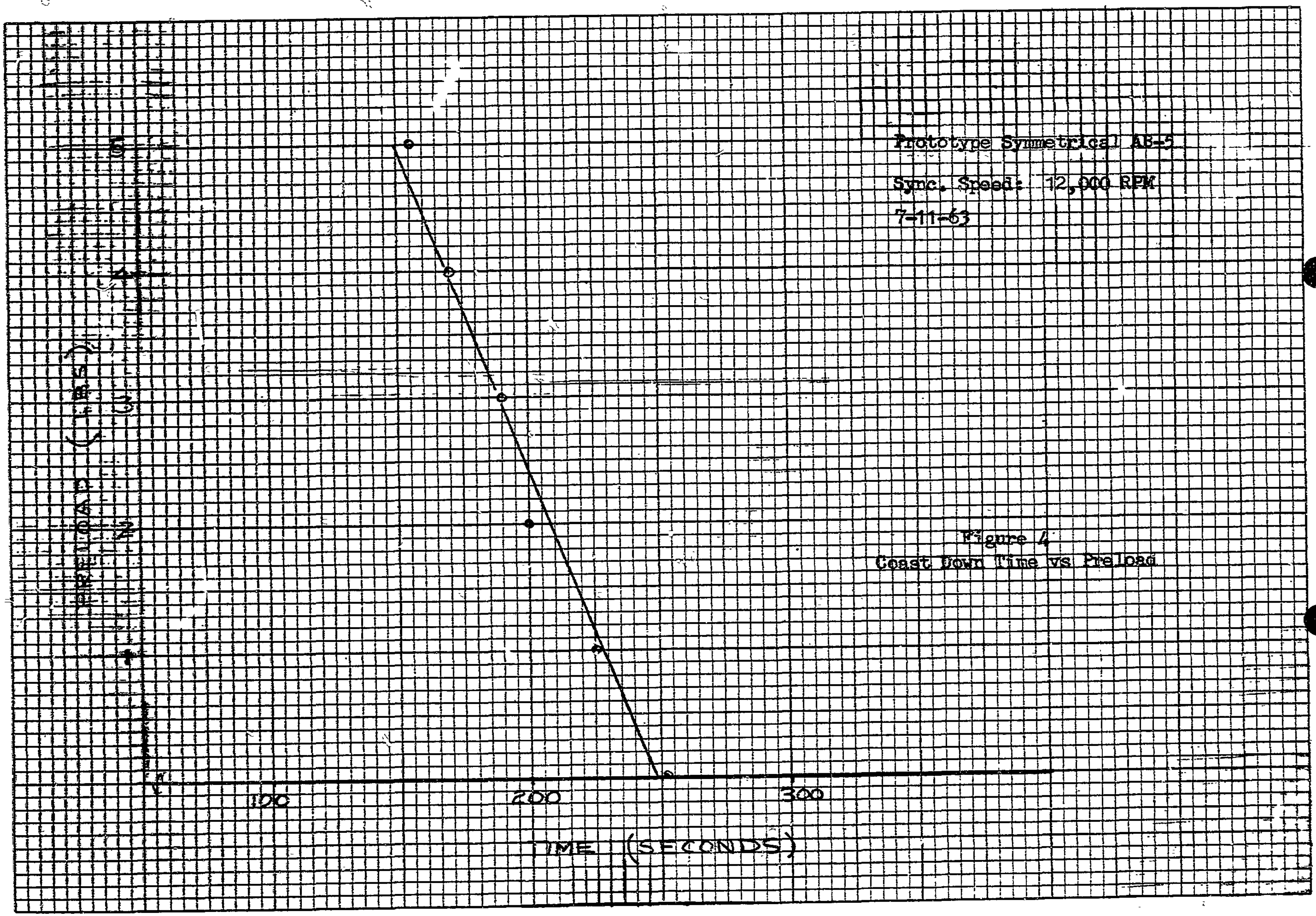
$\Delta L = +40 \times 10^{-6}$ inches (preload increasing)

Using a single side deflection of 20 x $10^{-6}$ inches and referring to the yield curve, this causes an increase of approximately 0.8 lb for an initial setting of 3.0 lb. Using the yield curve in a reverse manner, the beryllium construction requires an initial preload setting of 2.15 lb in order to have a resulting 3 lb preload at operating temperature.

Results of the analytical heat flow study were submitted in the March 1963 monthly report and are not repeated here.

2. <u>Preload Adjustment</u>

Preloading of the bearings is accomplished by lapping the bearing retainer until the desired coast down time is established. Figure 4 shows the relationship between the coast down time and the amount of preload. This curve was established by placing weights from 1 to 5 lbs in 1 lb increments directly on the outer race (so as to thrust load the bearings) and the coast down time was measured as the wheel coasted from synchronous speed to a complete stop under the various preloads.


Prototype Symmetrical AB-5
Sync. Speed: 12,000 RPM
7-11-63
Figure 4
Coast Down Time vs Preload
PRELOAD (LBS)
5
4
3
2
1
100
200
300
TIME (SECONDS)

## VI. Electron Beam Welding

Applications of the "Electron Beam Welding" process were considered in the basic design of the AB-5 gyro to secure the bearing shaft (52100 steel) to the flywheel (tungsten alloy) and to secure the hysteresis rings (GE, P-6) to the flywheel.

Samples of the materials to be welded were given to NASA for their evaluation using the Astrionics Laboratory electron beam welding machine. A satisfactory weld of these materials was not accomplished. However, in discussing this problem with NASA (Mr. Panzer on 12 July) it was learned that NASA had been experimenting with "Electron Beam Brazing." Since brazing is a recommended joining process for the tungsten alloy, it is very likely that an electron beam brazing process can be developed for joining the shaft and flywheel. This item is undergoing further investigation by NASA.

## VII. Conclusions and Recommendations

Briefly the conclusions of this task are as follows:

1. Induction Motor - The AB-5 induction motors were not as satisfactory as the hysteresis motors for the application intended and are not recommended for use in the AB-5 gyro.
2. Rotor Material - The GE P-6 magnetic hysteresis material is recommended for use in the rotor.
3. Stator - The 18 slot lamination of nickel-iron material (Carpenter 49) is recommended as being superior to the 12 slot silicon steel.

4. Unit Frame Construction - All available data indicates that the unit frame construction will be superior, especially in reducing thermal mass shift effects. It is recommended that a minimum of two assemblies be fabricated and drift tested. These units could be fabricated from aluminum or beryllium, however the use of beryllium is recommended since it will ultimately be the material of construction.

5. Electron Beam Welding - Since the electron beam welding process was not satisfactory, it is recommended that a brazing process be investigated in lieu of the welding. This work is to be continued by NASA Astrionics Laboratory using their electron beam facility.

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